NEW RESULTS FROM NA48 EXPERIMENT ON NEUTRAL KAON RARE DECAYS

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Recent results by the NA48 collaboration on neutral kaons rare decays into the $\pi^+\pi^-e^+e^-$ final state are presented. A large CP-violating asymmetry $\mathcal{A}(K_L) = (13.9 \pm 2.7 \pm 2.0)\%$ has been observed in the $K_L \to \pi^+\pi^-e^+e^-$ decay. The $K_S \to \pi^+\pi^-e^+e^-$ decay has been observed for the first time, showing no such asymmetry.

1 Introduction

The NA48 experiment at CERN SPS, described in detail elsewhere[1,2], has been designed to measure the direct CP violation parameter $\Re(\epsilon'/\epsilon)$ in two-pion decays of neutral kaons. However, the quality of its simultaneous K_L and K_S beams[3], high resolution detectors, fast trigger and performing data acquisition system allow to investigate at the same time rare decays of neutral kaons and neutral hyperons. Rare decay data have been collected during 1997-1999 $\Re(\epsilon'/\epsilon)$ runs, as well as during dedicated runs with a high intensity K_S and hyperon beam in 1999 and 2000.

In this talk I will report recent results from the NA48 experiment on K_L and K_S decays into the $\pi^+\pi^-e^+e^-$ final state, which provide a new opportunity to probe CP violation in the neutral kaon sector.

2 $K_L \to \pi^+\pi^-e^+e^-$

The e^+e^- pair in $\pi^+\pi^-e^+e^-$ decays of neutral kaons is expected to originate from a virtual photon[5,6]: $K_{L,S} \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$. The $K_L \to \pi^+\pi^-e^+e^-$ decay amplitude has two main components, one from CP-odd magnetic dipole (M1) direct photon emission, the other from the decay to the CP-even state $\pi^+\pi^-$ with inner bremsstrahlung. Interference between these amplitudes causes a large CP-violating asymmetry in the distribution of the angle φ between the normals to the $\pi^+\pi^-$ and e^+e^- planes in the kaon

c.m. system:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\varphi} = \Gamma_1 \cos^2(\varphi) + \Gamma_2 \sin^2(\varphi) + \Gamma_3 \sin(\varphi)\cos(\varphi) \ . \tag{1}$$

A non-zero value of Γ_3, i.e. a dependence of $\mathrm{d}\Gamma/\mathrm{d}\varphi$ on the sign of the CP-odd and T-odd variable $sin(\varphi)cos(\varphi)$, constitutes a clear signature of CP violation which can be seen in the $\mathrm{d}\Gamma/\mathrm{d}\varphi$ distribution. The CP-violating asymmetry

$$\mathcal{A} = \frac{N_{\sin(\varphi)\cos(\varphi)>0} - N_{\sin(\varphi)\cos(\varphi)<0}}{N_{\sin(\varphi)\cos(\varphi)>0} + N_{\sin(\varphi)\cos(\varphi)<0}} \tag{2}$$

is predicted by theory[5,6] to be $|\mathcal{A}(K_L)| = 15\%\cdot sin(\phi_{+-}+\delta_0(M_K^2)-\bar{\delta}_1) \approx 14\%$. The observation of such a large asymmetry has been reported recently[7] and found to be in agreement with theoretical predictions.

During 1998 and 1999 run periods more than 1300 good $K_L \rightarrow \pi^+\pi^-e^+e^-$ events have been selected using a dedicated four-track trigger[8]. The event identification relies on the precise tracking by the magnetic spectrometer and on the good energy resolution of the electromagnetic calorimeter for e/π separation. Background from $K_L \rightarrow \pi^+\pi^-\pi^0_D \rightarrow \pi^+\pi^-e^+e^-\gamma$ decays is strongly suppressed using a kinematic cut[4], while $\pi^+\pi^-e^+e^-$ events from two overlaid K_{e3} decays are rejected by time constraints. Electrons from photon conversions in the material before the spectrometer are eliminated by requiring a 2 cm minimum separation between the e^+ and e^- tracks in the first chamber.

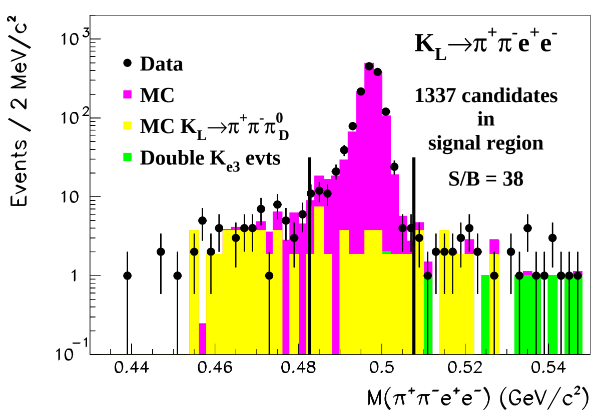

Figure 1. Invariant mass distribution of $K_L \rightarrow \pi^+\pi^-e^+e^-$ candidate events.

Figure 1 shows the invariant mass distribution of the $K_L \to \pi^+\pi^-e^+e^-$ candidate events passing all analysis cuts, together with the expected background contributions. For the determination of the $K_L \to \pi^+\pi^-e^+e^-$ branching fraction fully reconstructed $K_L \to \pi^+\pi^-\pi^0_D \to \pi^+\pi^-e^+e^-\gamma$ decays are used as normalization channel. The correction for the detector acceptance is determined using a model by Heiliger and Sehgal[6] with the inclusion of a form factor in the M1 direct emission amplitude:

$$F_{M1} = \tilde{g}_{M1}\left[1 + \frac{a_1/a_2}{(M_\rho^2 - M_K^2)c^2 + 2M_K(E_{e^+} + E_{e^-})}\right] \tag{3}$$

Using the values $\tilde{g}_{M1} = 1.35^{+0.20}_{-0.17}$ and $a_1/a_2 = (-0.720 \pm 0.029)$ $(\mathrm{GeV/c})^2$ measured by KTeV[7] we obtain the preliminary result $B(K_L \to \pi^+\pi^-e^+e^-) = (3.1 \pm 0.1 \pm 0.2) \cdot 10^{-7}$, in fair agreement with the KTeV preliminary result[9] of $(3.63 \pm 0.11 \pm 0.14) \cdot 10^{-7}$.

Figure 2 shows the $sin(\varphi)cos(\varphi)$ distribution of $K_L \to \pi^+\pi^-e^+e^-$ events after acceptance correction. Our preliminary result on the observed asymmetry is $\mathcal{A}(K_L) = (13.9 \pm 2.7 \pm 2.0)\%$, in good agreement with theoretical predictions[6] and the recently published KTeV value[7].

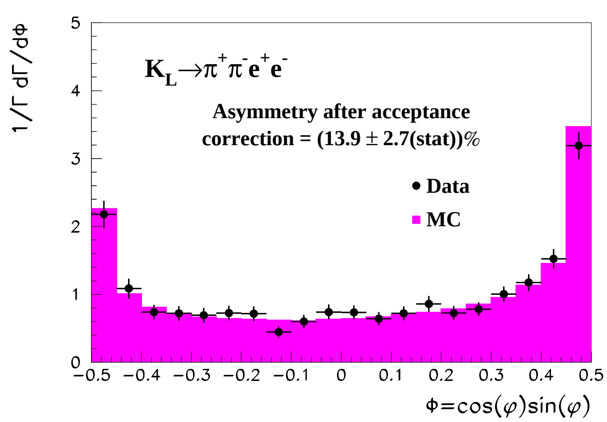

Figure 2. Acceptance corrected $sin(\varphi)cos(\varphi)$ distribution of $K_L \to \pi^+\pi^-e^+e^-$ candidate events.

3 $K_S \to \pi^+\pi^-e^+e^-$

The $K_S \to \pi^+\pi^-e^+e^-$ decay amplitude is largely dominated by the CP-even inner bremsstrahlung process, so no CP-violating asymmetry is expected in this case.

This decay mode has been observed for the first time with a clean sample of 56 events selected from 1998 data[8]. The decay events coming from the K_S beam have been selected using the very good vertex resolution of the magnetic spectrometer and the precise timing of the tagging detectors[10]. The invariant mass distribution of $K_S \to \pi^+\pi^-e^+e^-$ candidate events is shown in figure 3. Low invariant mass events in the plot are due to $K_L \to \pi^+\pi^-\pi^0_D \to \pi^+\pi^-e^+e^-\gamma$ decays of K_L mesons originating from the K_S target. Using 105 fully reconstructed $K_L \to \pi^+\pi^-\pi^0_D$ events from the K_S target as normalization channel from 1998 data a branching fraction $B(K_S \to \pi^+\pi^-e^+e^-) = (4.5 \pm 0.7 \pm 0.4) \cdot 10^{-5}$.

In 1999 two days of run were dedicated to the investigation of rare decays of K_S and neutral hyperons, with the proton beam intensity on the K_S target increased by about a factor 200, the K_L beam switched off and the AKS converter at the beginning of the fiducial volume removed. The large amount of rare decay events collected during this short test run, equivalent to several years of operation with the standard $K_L + K_S$ beam setup, allowed a more precise determination of the branching fraction and a measurement of the CP-violating asymmetry $\mathcal{A}(K_S)$ at a few percent level. The invariant mass distribution of $K_S \to \pi^+\pi^-e^+e^-$ candidate events from the full 1998+1999

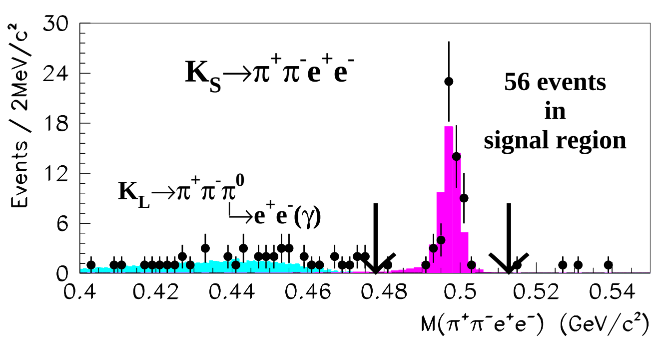

Figure 3. Invariant mass distribution of $K_S \to \pi^+\pi^-e^+e^-$ candidate events (1998 data).

data sample is shown in figure 4. The $sin(\varphi)cos(\varphi)$ distribution of these events is plotted in figure 5: the resulting asymmetry $\mathcal{A}(K_S) = (-0.2 \pm 3.4 \pm 1.4)\%$

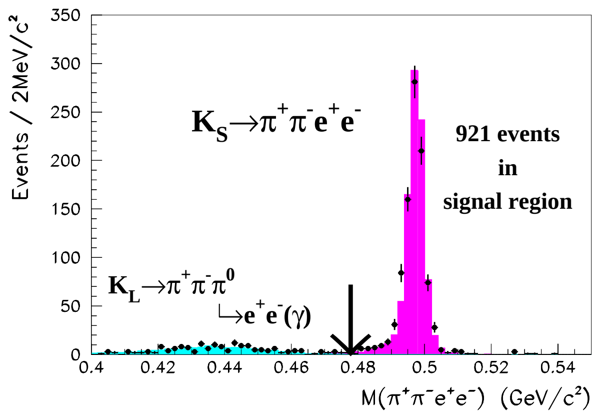

Figure 4. Invariant mass distribution of $K_S \to \pi^+\pi^-e^+e^-$ candidate events (1998+1999 data).

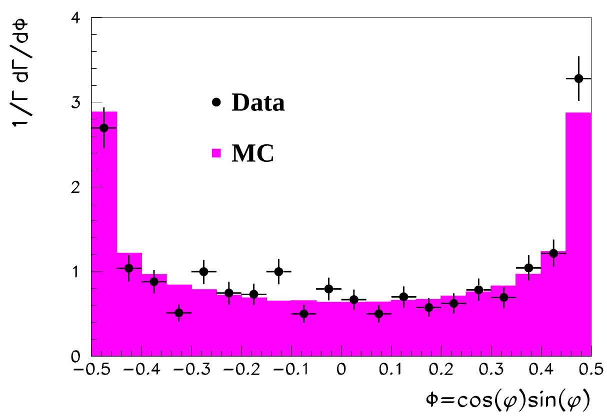

Figure 5. Acceptance corrected $sin(\varphi)cos(\varphi)$ distribution of $K_S \to \pi^+\pi^-e^+e^-$ candidate events (1998+1999 data).

is consistent with zero. Our preliminary result on the branching fraction is $B(K_S \to \pi^+\pi^-e^+e^-) = (4.3 \pm 0.2 \pm 0.3) \cdot 10^{-5}$. Using this number to evaluate the inner bremsstrahlung contribution to the K_L decay we obtain $B(K_L^{IB} \to \pi^+\pi^-e^+e^-) = (1.3 \pm 0.1) \cdot 10^{-7}$, in good agreement with theoretical expectations[5,6].

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